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Functional diversity of nematode communities in the Nizampatnam Bay, Bay of Bengal

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During the present study the relationship between taxonomic and biological trait approaches in relation to the abiotic environment were studied from the nematode samples collected from 64 subtidal stations during the four seasons in the Nizampatnam Bay, East coast of India. 19 categories of five biological traits known to represent an important ecological function were employed. These were related to buccal morphology, tail shape, body size, body shape and life history strategy. Data on trait membership was provided by biological information on species and genera. A total of 34 different trait combinations were recorded. In the present study, the most common morphotypes were non-selective deposit feeding nematodes, with colonizing abilities of 2-4 (in a scale of 1-5). Their abundance was correlated with depth. Inspite of a high turnover of species, functional diversity of assemblages did not change notably in space and time. A comparison of spatial and temporal patterns of nematode functional diversity between Nizampatnam Bay and other semi enclosed Bays in temperate and tropical regions suggests that two features are common: (1) in detecting spatial patterns, taxonomic approach is more powerful tool than biological trait approach; (2) biological trait approach offers more reliable correlative links with environmental factors than taxonomic one.

[**Key words**: Nematodes, meiobenthos, tropical environment, marine ecology, species diversity.]

Introduction

Analyses of biological traits of species and subsequent creation of functional groups have been introduced in studies focusing on assemblage structure. This relatively new approach allows obtaining insight into the functioning of ecosystems[15] and reveals additional relationships in assemblages[19]. They detected a positive relationship between number of species and functional diversity. An additional interesting point is that the relationship is also present at smaller spatial scales (i.e. few kilometers within a Bay) and in tropical ecosystems. The stations where nematode species were encountered in all the four seasons were considered for biological trait analyses and the matrix (numerical abundance vs. locations) was prepared on the basis of seasonal data from the overall mean derived for each location (Table 1).Marine nematode assemblages are generally compared by diversity indices and other species abundance patterns[13] regardless of the autecological requirements or identity of the taxa[23]. Species in functional groups share morphological traits that are thought or known to represent an important ecological function[7].

The present paper aims at testing how does the biological trait approach provide new interpretable information in comparison to a "classical" taxonomic approach of the nematode communities and which environmental variables control the community structure of nematodes in the Bay. In the present study 19 categories of five biological traits were used to represent an important ecological function.

Material and Methods

Nizampatnam Bay is an embayment in the Bay of Bengal and adjoins the Krishna river delta. Bay occupies an area of 1825 Sq.km in between latitudes 15° 25' to 15° 55' N and longitudes 80° 01' to 80° 50' E (Fig. 1). The coastline extends for about 122 Km from Kottapatnam in the southwest to

False Divi point in the northeast. River Krishna flows across the coastal plains and joins the sea at the northern end of the bay.

During this investigation, four cruises were conducted onboard using fishing trawler FKKD *Koti* representing sub-tidal (<50m) area from 10-30m depth of the shallow Bay. Sediment samples collected during four seasons, post-monsoon I, October, 2006 (N=80), pre-monsoon I, March 2007 (N = 48), post-monsoon II, November, 2007 (N =60) and pre-monsoon II, March 2008 (N=60) between latitudes 15° 28' to 15° 48' N and longitudes 80° 17' to 80° 47' E in the province of Nizampatnam Bay were used in the study**.**

A total number of 64 GPS located stations were covered during the four seasons. At each station, a glass corer (3.6 cm inner diameter) was used for collecting sediment samples of 10 cm long cores from grab (van Veen grab, $0.1 m^2$) hauls. Van Veen grab has an opening lid at the top, which facilitates the core sample to be taken out without disturbing the sediment. Replicate sub samples were collected from each haul. Samples were in Toto transferred to polythene containers, labeled and material preserved in 4% neutral formalin with Rose Bengal for further examination.

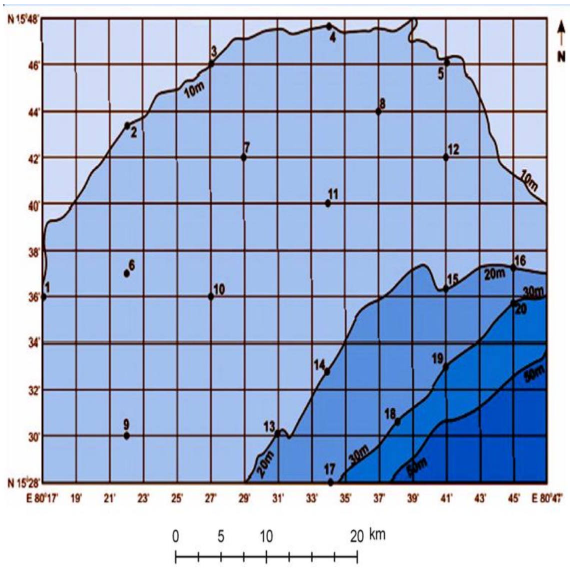

Fig. 1: Sampling locations along Nizampatnam Bay showing Cruise (FKKD Koti) track.

Observations on the physicochemical characteristics of the sea water (temperature, dissolved oxygen, salinity) were made according to Barnes[2]. Sediments (sub-samples) were oven dried (60°C) onboard and stored until further analysis. Samples were subjected to sieving and sediment texture (Master sizer 2000, Melvin Instruments, Germany) and proportions of sand, silt, and clay (%) were calculated and values were plotted on triangular graphs according to the nomenclature suggested by Sheppard[20]. Organic matter was estimated by the wet oxidation method of Walkey-Black but as modified by Gaudette et al [10].

To determine the proportions of nematodes with different biological traits, free-living marine nematode genera and species were classified into a series of biological traits according to Schratzberger et al[19] and references therein. A total of 19 categories of five biological traits, each of which was thought or known to represent an important ecological function, were assigned to each nematode genus or species. These biological traits were related to buccal morphology, tail shape, adult body size, body shape and life history strategy. A biological trait matrix was constructed by assigning to each nematode species / genus its affinity to each trait category. Biological trait matrix was then raised by the relative species abundance to give abundance – weighted trait matrices for each station (Table 1). Based on characteristics of buccal morphology, Wieser[25] devised a classification of feeding types for nematodes including selective deposit feeders consuming bacteria and small-sized organic particles (type 1A), non-selective deposit feeders also feeding on organic deposit but targeting larger sized particles (type 1B), epigrowth feeders scraping food off surfaces similar to macrobenthic grazers (type 2A), and predators feeding on nematodes and other small invertebrates (type 2B). Nematodes were assigned to four tail shape groups: short/round, elongated/filiform, conical and clavate, common in free-living marine nematodes from coastal environments according to Thistle and Sherman[22] and Thistle et al[23]. Thistle and Sherman[22] noted that nematode tails could be important in locomotion, feeding and reproduction. Adult length and the length–width ratio for adult nematode species were also deduced from the taxonomic literature. Nematode species were assigned to four length groups: <1 mm, 1–2 mm, 2–4 mm and >4 mm, and three shape categories: stout with a length–width ratio <18, slender with a length–width ratio of 18–72, and long/thin with a length–width ratio >72. Body size influences many aspects of an animal, such as its life history, physiology, energy requirements, and biotic and abiotic interactions[17, 6].

Table 1: Biological traits

Species	Buccal Morphology				Tail shape				Adult length				Adult shape			Life history (c-p score)			
	1A	1B	2A	2B	s/r	e/f	co	cl	>1	1to2	2to4	>4	st	sl	l/t	2	3	4	5
Enoploides sp.	0	0	0	1	0	0	0	1	0	1	0	0	0	1	0	1	0	0	0
Enoplolaimus longicaudatus	0	0	0	1	0	1	0	0	0	1	0	0	0	1	0	1	0	0	0
Enoplolaimus vulgaris	0	0	0	1	0	0	0	1	0	1	0	0	0	1	0	1	0	0	0
Phanoderma sp.	0	1	0	0	0	0	1	0	0	0	1	0	0	1	0	0	0	1	0
Leptosomatum sp.	0	1	0	0	1	0	0	0	0	0	0	1	1	0	0	0	0	0	1
Halalaimus gracilis	1	0	0	0	0	1	0	0	1	0	0	0	0	1	0	0	0	1	0
Halalaimus longicaudatus	1	0	0	0	0	1	0	0	1	0	0	0	0	0	1	0	0	1	0
Oxystomina asetosa	1	0	0	0	0	0	0	1	0	1	0	0	0	0	1	0	0	1	0
Metoncholaimus scanicus	0	0	0	1	0	0	0	1	0	0	1	0	0	1	0	0	0	1	0
Viscosia cobbi	0	0	0	1	0	0	0	1	0	0	1	0	0	1	0	0	1	0	0
Viscosia glabra	0	0	0	1	0	1	0	0	0	1	0	0	0	1	0	0	1	0	0
Viscosia elegans	0	0	0	1	0	0	0	1	0	1	0	0	0	1	0	0	1	0	0
Belbolla teissieri	0	0	0	1	0	0	0	1	0	1	0	0	0	1	0	0	0	1	0
Pareurystomina scilloniensis	0	0	0	1	0	1	0	0	0	1	0	0	0	0	1	0	0	1	0
Chromadora sp.	0	0	1	0	0	0	0	1	1	0	0	0	0	1	0	0	1	0	0
Rhips paraornata	0	0	1	0	0	0	1	0	1	0	0	0	0	1	0	0	1	0	0
Spilophorella sp.	0	0	1	0	0	0	1	0	1	0	0	0	0	1	0	1	0	0	0
Spilophorella candida	0	0	1	0	0	0	1	0	1	0	0	0	0	1	0	1	0	0	0
Spilophorella euxina	0	0	1	0	0	0	1	0	1	0	0	0	0	1	0	1	0	0	0
Dorylaimopsis sp.	0	0	1	0	0	0	1	0	0	1	0	0	0	1	0	1	0	0	0
Dorylaimopsis punctata	0	0	1	0	0	0	0	1	1	0	0	0	0	1	0	1	0	0	0
Paracomesoma dubium	0	1	0	0	0	0	1	0	1	0	0	0	0	1	0	1	0	0	0
Laimella sp.	0	0	1	0	0	1	0	0	1	0	0	0	0	1	0	1	0	0	0
Sabatieria lyonessa	0	1	0	0	0	0	0	1	1	0	0	0	0	1	0	1	0	0	0
Sabatieria elongata	0	1	0	0	0	0	0	1	1	0	0	0	0	0	1	1	0	0	0
Sabatieria pulchra	0	1	0	0	0	0	0	1	1	0	0	0	0	1	0	1	0	0	0
Sabatieria punctata	0	1	0	0	0	0	0	1	1	0	0	0	0	1	0	1	0	0	0
Setosabatieria sp.	0	1	0	0	0	0	0	1	1	0	0	0	0	1	0	1	0	0	0
Neotonchus sp.	0	0	1	0	0	0	1	0	1	0	0	0	0	1	0	0	1	0	0
Pomponema debile	0	0	1	0	0	0	0	1	1	0	0	0	0	1	0	0	0	1	0
Pomponema tesselatum	0	0	1	0	0	0	0	1	1	0	0	0	0	1	0	0	0	1	0
Nannolaimoides sp.	1	0	0	0	0	1	0	0	0	1	0	0	0	1	0	0	1	0	0
Paracanthonchus longicaudatus	0	0	1	0	0	1	0	0	1	0	0	0	0	1	0	1	0	0	0
Paracanthonchus caecus	0	0	1	0	0	0	0	1	1	0	0	0	0	1	0	1	0	0	0
Halichoanolaimus dolichurus	0	0	0	1	0	1	0	0	0	1	0	0	0	0	1	0	1	0	0
Richtersia discorda	0	1	0	0	0	0	1	0	1	0	0	0	1	0	0	0	1	0	0
Desmodora pilosa	0	0	1	0	0	0	1	0	1	0	0	0	0	1	0	1	0	0	0
Desmodora sp.	0	0	1	0	0	0	1	0	1	0	0	0	0	1	0	1	0	0	0
Desmodorella sp.1	0	0	1	0	0	0	1	0	1	0	0	0	0	1	0	1	0	0	0
Desmodorella sp.2	0	0	1	0	0	0	1	0	1	0	0	0	0	1	0	1	0	0	0
Onyx sp.	0	0	0	1	0	0	1	0	1	0	0	0	1	0	0	0	1	0	0

Contd…

	Buccal Morphology				Tail shape				Adult length				Adult shape			Life history (c-p score)			
Species	1A	1B	2A	2B	s/r	e/f	co	cl	>1	1to2	2to4	>4	st	sl	l/t	2	3	4	5
Monoposthia sp.	0	0	1	0	0	0	1	0	1	0	0	0	0	1	0	0	1	0	0
Ceramonema sp.	1	0	0	0	0	0	1	0	1	0	0	0	0	1	0	0	1	0	0
Tricoma brevirostris	1	0	0	0	0	0	1	0	1	0	0	0	1	0	0	0	0	1	0
Daptonema biggi	0	1	0	0	0	0	0	1	1	0	0	0	0	1	0	1	0	0	0
Daptonema invagiferoum	0	1	0	0	0	0	0	1	1	0	0	0	0	1	0	1	0	0	0
Daptonema vicinum	0	1	0	0	0	0	0	1	1	0	0	0	0	1	0	1	0	0	0
Daptonema procerum	0	1	0	0	0	0	0	1	1	0	0	0	0	1	0	1	0	0	0
Daptonema tenuispiculum	0	1	0	0	0	0	0	1	1	0	0	0	0	1	0	1	0	0	0
Theristus acer	0	1	0	0	0	0	1	0	1	0	0	0	0	1	0	1	0	0	0
Sphaerolaimus balticus	0	0	0	1	0	0	0	1	1	0	0	0	0	1	0	0	1	0	0
Sphaerolaimus islandicus	0	0	0	1	0	0	0	1	1	0	0	0	0	1	0	0	1	0	0
Sphaerolaimus macrocirculus	0	0	0	1	0	0	0	1	1	0	0	0	0	1	0	0	1	0	0
Parasphaerolaimus sp.	0	0	0	1	0	0	0	1	1	0	0	0	0	1	0	0	1	0	0
Astomonema southwardorum	1	0	0	0	0	0	1	0	1	0	0	0	1	0	0	0	1	0	0
Metalinhomoeus filiformis	0	1	0	0	0	0	1	0	1	0	0	0	0	1	0	1	0	0	0
Metalinhomoeus longiseta	0	1	0	0	0	1	0	0	0	1	0	0	0	0	1	1	0	0	0
Terschellingia gourbaultae	1	0	0	0	0	1	0	0	1	0	0	0	0	1	0	0	1	0	0
Terschellingia longicaudata	1	0	0	0	0	1	0	0	0	1	0	0	0	1	0	0	1	0	0
Axonolaimus paraspinosus	0	1	0	0	0	0	0	1	1	0	0	0	0	1	0	1	0	0	0
Axonolaimus spinosus	0	1	0	0	0	0	0	1	1	0	0	0	0	1	0	1	0	0	0
Parodontophora sp.	0	1	0	0	0	0	1	0	1	0	0	0	0	1	0	1	0	0	0

Smaller-sized species generally have higher growth rates[16], which are typical of opportunistic strategists. The differences in body shape of nematodes reflect an ecological adaptation designed to meet the conflicting requirements of either increased mobility (in slender body shape) to physical disturbance or reduced vulnerability (in stout body shape) to predation[21]. Nematodes were also allocated to life history groups according to Bongers[2] and Bongers et al[4, 5] where genera were classified on a five-point scale (1-5) from colonizers (inter alia short life-cycle, high reproduction rate high colonization ability and tolerant to various types of disturbance) to persisters (inter alia long-life-cycles, low colonization ability, few offspring and sensitive to disturbances). Maturity index (MI) can be calculated for each habitat/station based on c-p scores of inhabiting species using the formula[4].

$MI_{=\,i=1}\ \Sigma^S\ (v{*}f)$

Where S= number of species, v = the c-p value of taxon i and f = the frequency of that taxon.

The index of trophic diversity (ITD), based on the proportion of each of four feeding types, was calculated following Heip et al[11]. ITD values range from 0.25 (highest trophic diversity with the four trophic groups accounting for 25% each) to 1.0 (lowest trophic diversity when a single feeding type is present):

$$ITD = \Sigma\theta^2$$

Where θ = percent contribution of each four feeding types according to Wieser[25]: selective deposit feeders, non-selective deposit feeders, epistrate feeders and predators.

Non-metric multi-dimensional scaling (MDS) ordination using Bray-Curtis similarity measure was applied to relative abundance data to compare spatial patterns in the taxonomic and functional composition of nematode communities at the 64 sampling locations. Separate resemblance matrices were created based on the composition of the nematode communities with respect to species and genus identity, buccal morphology, tail shape, adult length, adult shape and coloniser-persister score. A further resemblance matrix was created based on the abundance-weighted biological traits matrix to summarise patterns in the functional structure of nematode assemblages of all species. Analysis of similarities (ANOSIM) was used to test the significant taxonomic and functional differences between stations and similarity percentages (SIMPER) procedure was applied to identify the trait groups that were primarily responsible for the functional differences observed between stations. The relationship between the structure of nematode assemblages and environmental variables was explored by calculating Spearman rank correlations (r_s) between similarity matrices derived from the faunal data (based on Bray – Curtis similarity) and matrices derived from various subsets of environmental data (based on normalized Euclidean Distance), thereby defining suites of environmental variables which best explained the biotic structure (BIOENV procedure). A permutation test was applied to assess the significance of these relationships.

Results

Among the stations studied in Nizampatnam Bay, depth ranged from 10 m to 34 m, % sand from 0.06 to 100%, silt content from 0.1 to 89%, clay content from 3.14 to 56.8%, organic matter content from 0.25 to 2.205%, mean particle diameter from 4.826 to 888 µm, bottom water temperature from 25 to 34 ^{0}C, salinity from 24.8 to 36.8 ^{0}C and dissolved oxygen from 1.344 to 5.824 ml.l^{-1} (Table 2).

Table 2: Environmental characteristics of Nizampatnam Bay with coefficient of determination

Variable	Min	Max	Mean	SE±
Depth (m)	10	34	18.3	0.9
Sand (%)	0	100	30.2	5.0
Silt (%)	0	89	48.6	3.7
Clay (%)	0	56.8	21.3	2.0
Org. matter (%)	0.25	2.205	1.2	0.1
MPD (µm)	4.826	888	153.7	30.9
Water. temp. (^{0}c)	25	34	29.4	0.2
Salinity (PSU)	24.8	36.8	32.2	0.4
Dissol. oxygen (ml.l^{-1})	1.344	5.824	3.6	0.1

Depth wise, at <15 m, the surface water dissolved oxygen ranged from 2.74 ml.l^{-1} (sts.1 and 2, pre-monsoon II) to 7.56 ml.l^{-1} (st.4, post-monsoon II), mean 4.32±0.20 and at >15 m depth, the surface water dissolved oxygen varied from 2.58 ml.l^{-1} (sts.14 and 16, pre-monsoon II) to 6.05 ml.l^{-1} (st.16, post-monsoon II), mean 3.93±0.18. At <15 m, the bottom water dissolved oxygen ranged from 1.34 ml.l^{-1} (st.9, post-monsoon I) to 5.82 ml.l^{-1} (st.6, post-monsoon II), mean 3.69±0.17 and >15 m ranged from 1.76 ml.l^{-1} (st.20, pre-monsoon I) to 4.93 ml.l^{-1} (sts.15, 16 and 17, post-monsoon II), mean 3.60±0.15. It’s clearly evident from the above findings that surface and bottom water dissolved oxygen concentrations declined with an increase in depth (Fig. 2).

Fig. 2: Temperature (^{0}C), Salinity (PSU) and Dissolved Oxygen (ml.l^{-1}) from Nizampatnam Bay at different depths

Table 3: List of species ranked by dominance (feeding types after Wieser, 1960) during the different seasons in the Nizampatnam Bay

Species	Feeding habitat	Post monsoon I	Pre monsoon I	Post monsoon II	Pre monsoon II	Total	Abundance relative (%)	Abundance cumulative (%)
Enoploides sp.	2B	1	0	2	4	7	0.15	0.15
Enoplolaimus longicaudatus	2B	2	3	1	5	11	0.24	0.38
Enoplolaimus vulgaris	2B	0	0	2	5	7	0.16	0.54
Phanoderma sp.	1B	0	0	0	1	1	0.02	0.57
Leptosomatum sp.	1B	3	4	4	10	21	0.46	1.03
Halalaimus gracilis	1A	12	7	8	5	32	0.72	1.75
Halalaimus longicaudatus	1A	25	23	16	21	84	1.90	3.65
Oxystomina asetosa	1A	24	11	5.5	7	47.5	1.07	4.72
Metoncholaimus scanicus	2B	0	3	1	4	8	0.18	4.91
Viscosia cobbi	2B	90	22	31	25	167	3.76	8.67
Viscosia glabra	2B	11	13	10	13	47	1.06	9.73
Viscosia elegans	2B	0	1	4	11	16	0.35	10.08
Belbolla teissieri	2B	10	10	0	10	30	0.67	10.75
Pareurystomina scilloniensis	2B	1	0	3	2	6	0.14	10.89
Chromadora sp.	2A	0	0	0	2	2	0.05	10.93
Rhips paraornata	2A	32	14	21	22	88	1.99	12.92
Spilophorella sp.	2A	8	10	8	8	34	0.77	13.69
Spilophorella candida	2A	63	46	42	38	188	4.24	17.93
Spilophorella euxina	2A	159	52	56	34	300	6.77	24.70
Dorylaimopsis sp.	2A	1	7	14	22	44	0.98	25.68
Dorylaimopsis punctata	2A	217	129	110	169	624	14.10	39.78
Paracomesoma dubium	1B	35	11	24	81	151	3.40	43.18
Laimella sp.	2A	8	6	9	11	34	0.77	43.95
Sabatieria lyonessa	1B	13	7	0	5	25	0.57	44.51
Sabatieria elongata	1B	0	0	22	23	45	1.02	45.53
Sabatieria pulchra	1B	62	28	30	16	136	3.06	48.59
Sabatieria punctata	1B	183	127	110	125	545	12.31	60.90
Setosabatieria sp.	1B	8	0	0	9	17	0.38	61.29
Neotonchus sp.	2A	0	0	0	3	3	0.07	61.35
Pomponema debile	2A	0	3	11	9	23	0.51	61.86
Pomponema tesselatum	2A	0	0	6	0	6	0.14	62.00
Nannolaimoides sp.	1A	14	0	9	2	25	0.55	62.55
Paracanthonchus longicaudatus	2A	0	1	13	18	32	0.71	63.26
Paracanthonchus caecus	2A	0	0	0	3	3	0.07	63.33
Halichoanolaimus dolichurus	2B	2	0	2	8	12	0.27	63.60
Richtersia discorda	1B	1	0	0	0	1	0.02	63.63
Desmodora pilosa	2A	1	1	7	3	12	0.27	63.90
Desmodora sp.	2A	10	7	0	0	17	0.38	64.28

Species	Feeding habitat	Post monsoon I	Pre monsoon I	Post monsoon II	Pre monsoon II	Total	Abundance relative (%)	Abundance cumulative (%)
Desmodorella sp.1	2A	2	5	2	0	9	0.20	64.49
Desmodorella sp.2	2A	5	6	0	3	14	0.32	64.80
Onyx sp.	2B	0	2	3	0	5	0.11	64.91
Monoposthia sp.	2A	7	0	4	4	15	0.34	65.25
Ceramonema sp.	1A	0	0	0	1	1	0.02	65.28
Tricoma brevirostris	1A	6	4	4	3	17	0.38	65.66
Daptonema biggi	1B	0	17	0	9	26	0.58	66.24
Daptonema invagiferoum	1B	8	8	8	9	33	0.75	66.98
Daptonema vicinum	1B	102	22	38	63	225	5.08	72.06
Daptonema procerum	1B	38	9	25	25	97	2.18	74.24
Daptonema tenuispiculum	1B	0	1	0	0	1	0.02	74.26
Theristus acer	1B	0	3	4	1	8	0.18	74.44
Sphaerolaimus balticus	2B	69	42	47	27	184	4.16	78.60
Sphaerolaimus islandicus	2B	0	0	2	6	8	0.18	78.78
Sphaerolaimus macrocirculus	2B	20	20	22	34	96	2.16	80.94
Parasphaerolaimus sp.	2B	13	10	12	5	40	0.89	81.84
Astomonema southwardorum	1A	0	3	2	0	5	0.11	81.95
Metalinhomoeus filiformis	1B	0	1	0	0	1	0.02	81.97
Metalinhomoeus longiseta	1B	135	64	132	115	444	10.04	92.01
Terschellingia gourbaultae	1A	1	1	2	0	4	0.09	92.10
Terschellingia longicaudata	1A	22	11	11	2	46	1.03	93.13
Axonolaimus paraspinosus	1B	61	46	57	78	241	5.45	98.58
Axonolaimus spinosus	1B	12	3	17	10	42	0.95	99.53
Parodontophora sp.	1B	0	0	0	21	21	0.47	100.00
Total		1492	818	969	1145	4424	100.00	

Functional attributes of nematode communities in the Nizampatnam Bay are listed in Table 3. The proportions of feeding types of nematodes in the Bay were obtained in relation to depth, in which nematodes were dominated by non-selective deposit feeders (1B) and epistrate feeders (2A) where as proportions of predators (2B) and selective deposit feeders (1A) were comparatively low at most stations. Season wise, non-selective deposit feeders and epigrowth feeders were the first and second abundant groups.

The selective deposit feeders (1A) were *Halalaimus gracilis, Oxystomina asetosa, Nannolaimoides* sp., *Tricoma brevirostris and Terschellingia longicaudata,* non-selective deposit feeders (1B) include *Sabatieria punctata, Sabatieria lyonessa, Setosabatieria* sp.*, Richtersia discorda, Daptonema invagiferoum, Daptonema biggi, Daptonema vicinum, Axonolaimus spinosus, Axonolaimus paraspinosus* and *Parodontophora* sp., The epistrate feeders (2A) were *Dorylaimopsis punctata, Pomponema debile, Paracanthonchus longicaudatus, Desmodora pilosa* and *Monoposthia* sp., where as predators/omnivores (2B) include *Enoploides* sp., *Enoplolaimus longicaudatus, Viscosia cobbi, Halichoanolaimus dolichurus* and *Sphaerolaimus balticus.* Thus, most of the nematodes in Nizampatnam Bay were non-selective deposit feeders (1B).

Season wise, the ratio was different among stations ranging from 0.60 (post-monsoon I) to 4.43 (pre-monsoon I). The highest ratio was observed in the pre-monsoon I and the lowest ratio was observed in the post-monsoon I. This indicates that organic detritus was abundant in the pre-monsoon I and II (Fig. 3).

Clavate tail (type 4) was observed for most of the nematodes (59.8%) and it was the most prevalent tail shape at the majority of stations, while the conico cylindrical and long/filiform tail shaped (type 2 and 3) occupies the second place (39.9%). Nematodes with long, retractable tails may be able to feed toward the surface where food is relatively more abundant while retaining the ability to retreat rapidly[18, 9]. They can also avoid surface predators and resuspension in the noncatastrophic erosive flows. The body shape of the nematodes was mainly slender occupying 90% of total nematodes and in less proportion long/thin and stout animals which were shown in Tables 4 and 5.

The average adult lengths of nematodes ranged from 0.20 mm to 2.04 mm. The majority (79%) of nematode individuals were recorded in the length class (<1 mm), followed by the length class (1-2 mm) was 20% and the nematode individuals for (2-4 mm) length class was 0.5%. In contrast, there was 51% of same length class occurring in subtropical Hong Kong [13].

Three nematode morphotypes were encountered in the present study. The majority of nematodes were slender (90%), followed by long/thin (9%) and stout animals (1%). High dominance of non-selective deposit feeders (1B) and epistrate feeders (2A) encountered at stations 4, 12 and 14. The nematode communities collected at stations 4 and 12 were highly dominated by individuals with clavate tail, whereas at station 14, they were highly dominated by the elongated/filiform tail. The Maturity Index (MI) in overall composition of nematodes varied between 0.008 (sts. 15 and 16, post-monsoon II) and 0.165 (st.4, pre-monsoon II). In general, post-monsoon II season have high maturity index (2.28) followed by pre-monsoon I (2.19), pre-monsoon II (2.17) and post-monsoon I (2.06).

Spatial differences in the trophic structure of nematode assemblages were primarily exerted via changes in the dominance patterns of selective deposit feeders versus non-selective deposit feeders and epigrowth feeders. Despite these differences in food selection, the ITD demonstrated similar values in the Bay. Season wise, ITD values varied significantly, 0.07 (pre-monsoon I), 0.08 (post-monsoon I), 0.16 (pre-monsoon II) and 0.20 (post-monsoon II) (Table 6).

Over 76% of all identified individuals attained a coloniser-persister score of 2 while the remaining have a c-p score of 3. Extreme persisters (coloniser-persister score of 5), in contrast were either absent or rare. Nematode communities were clearly dominated by families with colonizer-persister values of two to four (c-p 2 to 4). In subtropical Hong Kong, the colonizer-persister (c-p) score 2 was most dominant (81%)[14]. However, in the North Sea, over 81% of all identified individuals attained a colonizer-persister score of 2 or 3[19].

Table 4: Relative abundance (mean±SE) of nematodes in buccal morphology and tail shape categories in the Nizampatnam Bay

Station	Buccal morphology				Tail shape			
	1A	1B	2A	2B	Short/round	Elongated/filiform	Conical	Clavate
1	3±1	28±8	20±7	7±1	0±0	20±12	15±8	22±6
2	4±1	23±8	15±4	4±1	0±0	11±4	9±2	26±6
3	6±1	27±3	20±4	7±2	2±1	11±2	13±2	35±6
4	8±2	84±38	51±17	22±10	2±0	27±11	43±18	94±36
5	7±0	49±0	33±0	12±0	0±0	15±0	23±0	63±0
6	9±6	35±6	31±7	18±6	1±0	13±4	25±5	53±10
7	3±0	29±0	20±0	12±0	0±0	11±0	11±0	41±0
8	2±0	15±0	15±0	9±0	0±0	8±0	6±0	27±0
9	7±2	35±17	25±7	14±5	0±0	24±13	14±3	42±17
10	5±2	47±16	16±9	7±3	0±0	10±1	8±5	55±17
11	7±0	60±0	53±0	7±0	2±0	2±0	28±0	95±0
12	3±1	39±4	28±5	14±5	0±0	8±3	18±5	58±7
13	7±3	31±5	17±5	8±3	0±0	13±3	5±4	42±10
14	2±0.2	41±13	26±12	23±8	2±1	14±4	23±14	50±16
15	2±1	21±7	13±4	10±3	0±0	11±2	12±5	19±5
16	4±3	15±3	12±3	7±2	0±0	6±2	7±3	22±4
17	4±1	21±6	18±5	9±1	0±0	12±2	10±3	30±6
18	4±1	30±6	34±9	11±3	0±0	14±3	18±4	47±12
19	2±1	20±6	12±1	5±2	0±0	8±3	5±2	24±6
20	2±1	24±6	13±3	9±2	0±0	10±5	4±1	30±6

Table 5: Relative abundance (mean±SE) of nematodes in adult length, adult shape and life history categories

Station	Adult length				Adult shape			Life history			
	>1mm	1-2mm	2-4mm	>4mm	Stout	Slender	Long/thin	c-p 2	c-p 3	c-p 4	c-p 5
1	51±14	5±1	1±0	0±0	1±0	53±15	7±3	45±13	8±1	4±1	0±0
2	35±9	10±4	2±1	0±0	1±0	38±10	9±7	35±10	7±2	3±0	1±0
3	45±6	13±2	2±0	0±0	2±1	51±9	7±3	45±5	8±1	7±1	1±0
4	132±53	28±12	3±1	0±0	2±1	146±56	22±13	131±55	26±9	7±3	2±0
5	83±0	17±0	0±0	0±0	1±0	92±0	8±0	82±0	17±0	2±0	0±0
6	72±12	12±4	8±2	0±0	1±0	83±12	15±4	61±10	24±9	5±3	1±0
7	49±0	11±0	4±0	0±0	0±0	55±0	8±0	46±0	17±0	0±0	0±0
8	32±0	9±0	0±0	0±0	0±0	35±0	6±0	36±0	5±0	0±0	0±0
9	56±18	21±11	0±0	0±0	3±1	75±30	6±0	56±22	16±9	8±1	0±0
10	62±21	12±0	0±0	0±0	0±0	66±17	8±5	61±23	9±1	5±1	0±0
11	113±0	5±0	7±0	0±0	2±0	120±0	5±0	104±0	14±0	7±0	2±0
12	68±10	12±2	6±2	0±0	0±0	78±11	6±3	66±10	12±2	7±2	0±0
13	48±13	10±3	4±1	0±0	0±0	55±12	5±3	48±10	10±5	3±1	0±0
14	67±25	13±5	9±6	0±0	2±1	80±31	9±4	65±25	26±9	2±0	2±1
15	28±8	10±2	0±0	0±0	0±0	33±9	12±1	30±8	9±4	3±1	0±0
16	28±6	6±2	4±1	0±0	1±0	34±7	3±1	26±4	6±2	4±1	0±0
17	40±9	9±1	4±2	0±0	2±1	47±9	5±3	36±9	12±1	4±1	0±0
18	66±15	11±2	5±1	0±0	0±0	75±19	6±2	61±14	11±3	7±3	0±0
19	28±5	8±3	2±1	0±0	0±0	32±4	6±3	31±7	5±1	2±1	0±0
20	34±6	12±5	4±0	0±0	0±0	38±6	15±1	37±8	10±1	1±0	0±0

Fig. 3: Trophic composition of nematode assemblages on basis of average percentages of Nizampatnam Bay in overall, season wise and depth wise. The feeding types defined after Weiser (1953): 1A= selective deposit feeders, 1B= non-selective deposit feeders, 2A=epistratefeeders, 2B=predators/omnivores

In contrast to terrestrial environments, extreme colonizers (colonizer–persister score of 1) and persisters (colonizer–persister score of 5) were rare or absent in this study. From the data it was possible to plot the data points in a c-p triangle, as suggested by De Goede et al[8], however, the proportions of c-p 2, c-p 3 and c-p 4 were used as ordinations to distinguish the sites. In Fig. 4 mainly two groups can be separated. The stations 1-5, 8-13, 15, 16 and 18-20 shows a higher proportion of c-p 2 taxa namely *Enoploides* sp., *Enoplolaimus longicaudatus, Spilophorella candida, Sabatieria punctata and Daptonema biggi,* the stations 6, 7, 14 and 17 can clearly be distinguished from the other sites by its high proportion of c-p 3 namely *Viscosia cobbi, Rhips paraornata, Nannolaimoides* sp., *Halichoanolaimus dolichurus.* The colonizer-persister (c-p 5) taxa *Leptostomatum* sp., were encountered at stations 2, 3, 4, 6 and 11 (< 15 m depth) and c-p 1 was practically absent**.**

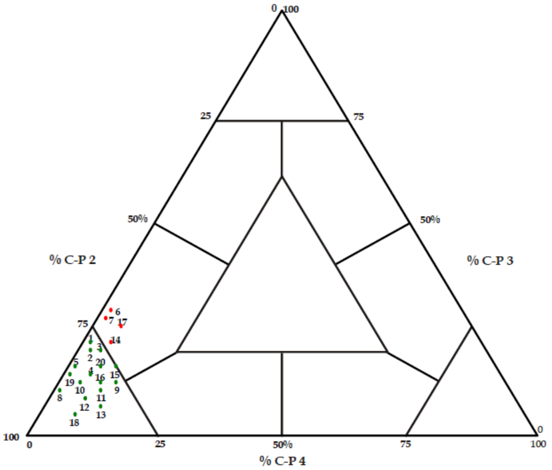

Fig. 4: Relative abundance of nematode taxa classified as c-p 2, c-p 3 and c-p 4 (c-p 5 taxa were omitted from the calculation): data points represent mean values of sampling sites

Coloniser – persister score of 4 represented by 8 genera (*Phanoderma* sp., *Halalaimus gracilis, Oxystomina asetosa* and *Pomponema debile*), coloniser – persister score of 3 represented by 13 genera (*Viscosia cobbi, Halichoanolaimus dolichurus, Sphaerolaimus balticus* and *Terschellingia longicaudata*), coloniser – persister score of 2 represented by 17 genera (*Enoploides* sp., *Dorylaimopsis punctata*, *Sabatieria punctata* and *Daptonema vicinum*) and coloniser – persister score of 5 represented by single genera i.e., *Leptosomatum* sp. were encountered. A total of 34 different combinations of biological traits were observed from the 62 species of nematode communities.

Discussion

Nematode assemblages collected at the 64 sub tidal stations differed both taxonomically and functionally but the ordinations of taxonomic groups did not match the ordinations based on functional groups and traits. In the ordinations based on the relative abundance of nematode genera and species, stations at <15 m (sts. 1 to 12) tended to cluster into one group and the stations in the >15 m (sts. 13 to 20) formed into another group. This geographic separation was less pronounced in the ordinations derived from functional characteristics of nematode communities (Fig. 5).

A total number of 34 different combinations of biological traits, and 53 species shared the two most common combinations of traits (Table 1). The biological matrix revealed several notable relationships between traits. The slender nematodes were also dominant (82%) in the North Sea study by Schratzberger et al[18] and (93-98%) dominant in subtropical Hong Kong studied by Liu et al[13]. For example, large bodied nematodes generally had a high colonizer-persister score while that for smaller species was low. Equally, in contrast to the generally small-sized selective deposit feeders, predators were usually large. While ecologically implausible trait combinations such as, for example, small body size combined with a K-selected life history strategy (i.e. high colonizer-persister score) were absent from the nematode communities of Nizampatnam Bay. There were no clear spatial pattern of biological traits (i.e. feeding types, tail shape and body shape) within the sediments.

Results from ANOSIM analyses: Global R of differences between nematode assemblages in the Nizampatnam Bay.

Species	0.405
Genus	0.237
Buccal morphology	0.055
Tail shape	0.041
Adult size	0.039
Adult shape	0.049
Life history strategy	0.051

All R- values were significant at p<0.01

Table 6: Index of trophic diversity (ITD) and Maturity Index (MI) for nematodes at selected locations of Nizampatnam Bay

Name of station	Index of trophic diversity (ITD)	Maturity index (MI)	Name of station	Index of trophic diversity (ITD)	Maturity index (MI)
Post-monsoon I			Pre-monsoon I		
1	0.25	0.07	1	0.25	0.13
2	0.25	0.04	2	0.25	0.09
3	0.25	0.09	3	0.25	0.24
4	0.25	0.08	4	0.25	0.20
5	0.25	0.16	5	--------No sampling------	
6	0.25	0.22	6	0.25	0.31
7	0.25	0.10	7	--------No sampling------	
8	0.25	0.06	8	--------No sampling------	
9	0.25	0.08	9	0.25	0.21
10	0.25	0.15	10	0.25	0.17
11	0.25	0.20	11	--------No sampling------	
12	0.25	0.19	12	0.25	0.17
13	0.25	0.15	13	--------No sampling------	
14	0.25	0.28	14	0.25	0.20
15	0.25	0.10	15	--------No sampling------	
16	0.75	0.07	16	0.25	0.16
17	0.25	0.13	17	0.25	0.19
18	0.25	0.12	18	0.25	0.30
19	0.25	0.07	19	0.25	0.07
20	0.25	0.10	20	0.5	0.05

Name of station	Index of trophic diversity (ITD)	Maturity index (MI)	Name of station	Index of trophic diversity (ITD)	Maturity index (MI)
Post-monsoon II			Pre-monsoon II		
1	0.25	0.10	1	0.25	0.21
2	0.25	0.17	2	0.25	0.15
3	0.25	0.17	3	0.25	0.10
4	0.25	0.56	4	0.25	0.72
5	--------No sampling------		5	--------No sampling------	
6	0.25	0.14	6	0.25	0.19
7	--------No sampling------		7	--------No sampling------	
8	--------No sampling------		8	--------No sampling------	
9	0.25	0.49	9	0.25	0.09
10	--------No sampling------		10	--------No sampling------	
11	--------No sampling------		11	--------No sampling------	
12	0.25	0.15	12	0.25	0.20
13	0.25	0.10	13	0.75	0.11
14	0.75	0.05	14	0.25	0.19
15	0.75	0.04	15	0.75	0.11
16	0.25	0.04	16	0.75	0.03
17	0.25	0.10	17	0.25	0.07
18	0.25	0.28	18	0.25	0.06
19	0.75	0.07	19	0.25	0.10
20	0.75	0.10	20	0.25	0.12

Fig. 5: Non-parametric multi-dimensional scaling (MDS) ordination based on the relative abundance of nematode species, genera and functional groups (Depth 1: <15m and Depth 2: >15m)

Nematode distribution patterns based on proportions of species and biological traits were linked to depth, dissolved oxygen and salinity. The composition of assemblages in terms of biological traits was best explained by a combination of factors like depth, salinity and dissolved oxygen. Environmental conditions thus influence the importance of functional complementarity structuring communities[12].

Relationships of nematodes with abiotic environment: BIOENV procedure was applied on similarity matrices derived from density data for nematode species, individual biological traits (e.g. feeding type, life history strategy, tail shape, and body size) and a combination of four traits. Interestingly matrix of similarity based on taxonomic and functional diversity was correlated with depth, salinity and dissolved oxygen.

Species	0.323	1, 4, 3
Genus	0.203	1, 4, 3
Buccal morphology	0.145	1, 3, 4
Tail shape	0.141	3, 4, 1
Adult size	0.166	1, 4, 3
Adult shape	0.174	1, 3, 4
Life history strategy	0.172	3, 4, 1

1. Depth; 2. Temperature; 3. Salinity; 4. Dissolved oxygen; 5. Sand; 6. Silt; 7. Clay; 8. MPD (mean particle diameter); 9. Organic matter.

Conclusion

Functional diversity is an important component of biodiversity, yet in comparison to taxonomic diversity, methods of quantifying functional diversity are less well developed [16]. The results from the MDS showed that assigning species and genera to biological traits provided additional insights to those from traditional taxonomic analyses. Improving our understanding of diversity function relationships across ecosystems will require a categorization of species attributes that can be related to function. Consequently, obtaining a greater knowledge of the functional roles of nematode species will be the key to improve the sensitivity and interpretation of 62 nematode species identified in the biological traits analyses of marine benthic communities in the present study.

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